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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Method and Apparatus for Logging Boreholes.

We, KOOLAJIPARI TROSZT, a Corporate Body organised under Hungarian law, of 11 Szent Istvan korut, Budapest, Hungary, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates a method and apparatus for lagging boreholes.

As is known, the various physical parameters of formations penetrated by boreholes can be indirectly determined by electrical resistivity survey (electrical well logging). The electrical resistivity of formations penetrated by a borehole is conventionally measured by using two current electrodes fed by one current source from which electric currents flow into the borehole down to the level to be surveyed, and by measuring the potential difference developed by the current between two measuring electrodes. Such measuring can be performed either by lowering all four electrodes to the survey level, or by using only three electrodes down the hole in which case one current electrode or one measuring electrode is earthed at the surface.

When the electrical resistivity measurement is performed by passing direct currents to the electrodes the potentials appearing at the level of the different formations (so-called natural potentials) cannot be separated from the values of the surveyed potential, and the measurement is thus disturbed. In a known method the potential is measured by means of direct currents, and the intensity of the surveying current is so chosen that the induced potential between the measuring electrodes is larger by one order at least than the self potentials. In a development of the same method the survey currents are periodically interrupted and in the intervals the natural potential is measured and recorded. None of these methods can master the task of separation of the potentials in practice because when surveying by direct current, not only the spontaneous potentials but also the induced electro-mechanical potentials act to disturb the measurement.

To avoid the disturbing effect of the spontaneous and induced electro-mechanical potentials it is necessary to make use of alternating current for the survey. The use of sinusoidal A.C. is handicapped by the survey current flowing through the core of the well logging cable which causes a disturbing voltage of varying amplitude between the cable cores connecting the survey electrodes and the measuring circuit at the surface. This has a distorting effect on the measured result.

Thus in practice the application of sinusoidal survey current is largely limited to cases in which a generator inducing survey current or an amplifier for reinforcing the measured potential is placed in the borehole near the electrodes. Using a part of the survey equipment as a down-hole instrument proved inconvenient in practice. According to a method which is considered at present the most suitable, the measuring is generally performed by means of square-waveformed survey current of alternating polarity provided by an electromechanical converter (a so-called pulsator) from D.C. voltage. In the course of this method an induced disturbance or noise-voltage arises only in the periods of rise and fall of the square wave edges, when a survey current of square waveform is used. For the elimination of this noise-voltage a pulsator section, synchronised with the pulsator section associated with the feeding current, switches on

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the survey cable contacting the measuring circuit only after the rise of the leading edge of the survey currents, and switches it off before the fall of the trailing edge. Thus the measuring circuit is only connected to the cable when the intensity of the survey current is constant, and no induced disturbing voltage appears in the measuring circuit.

It is a detrimental feature of the above, rather widely used measuring method that it involves the use of an electro-mechanical converter. The latter instrument, even when made with the utmost care and precision, is an unfavourable and unstable piece of apparatus, and may constitute a permanent source of errors. Besides, in most cases neither its frequency stability nor its frequency adjustment are satisfactory. Since the frequency range covered by a mechanical pulsator is also very small, mutli-channel measurements at several different frequencies cannot be made. Moreover, the pulsator leads may also cause various errors in the measurements.

Accordingly the present invention provides a method of logging a borehole including the steps of sending low frequency sinusoidal alternating current through the ground between two current electrodes, providing a number of measuring electrodes down the borehole, providing frequency and phase selective amplifier means at the surface of the ground and connected to said measuring electrodes to receive therefrom voltage signals corresponding to said current, providing a resistor connected in series with one of the current electrodes, and supplying the amplified voltage signals to recording means, said resistor and said one current electrode being located in the borehole and said amplifier means being frequency selective so as to provide an amplified output of voltage signals substantially at said frequency and of a predetermined phase relationship to said current and to attenuate signals at other frequencies, and the value of said resistor being such that the maximum value of the alternating current is maintained substantially constant.

The present invention also provides apparatus for logging a borehole which is capable of making a number of simultaneous measurements of electrical resistivity including a signal generator located, in operation, on the surface for sending low frequency sinusoidal alternating current through the ground between two current electrodes, a resistor connected in series with one of the current electrodes, said resistor being located with respect to said one current electrode so that when in operation both are located within the borehole, and a plurality of pairs of measuring electrodes, at least one electrode of each pair being arranged, in operation, in the borehole, each pair of measuring electrodes being connected to a respective one of a plurality of phase selective circuit means equal in number to the number of simultaneous measurements to be made.

Those disturbing voltage components having a reactive phase which are capacitatively or inductively induced due to the sinusoidal current flowing through the conductors between the generator and feeding points are eliminated, as well as other disturbing voltages. This solution permits sinusoidal measuring current to be used whilst both the survey-current generator and the measuring circuits can be arranged on the surface.

If desired two or more sondes (complete electrode-carrying assemblies) may be provided in a borehole at the same time and at different depths to make measurements at different depths, the major part of the equipment being located on the surface. The measurement of the resistivity of the earth formations is performed by sending a sinusoidal survey current of constant intensity between two feeding points, and from the potential generated between two measuring points the voltage component, which has the same frequency and phase position as the measuring current, is measured, while attenuation of the quadrature (as compared to the survey current) reactive disturbing voltage component is secured.

Furthermore it is possible to simultaneously make recordings for two or more resistivity slices, using a minimum of leads, and to locate the equipment on the surface.

Some embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:—

Fig. 1 is a diagrammatic representation of apparatus suitable for the recording of one resistivity measurement in a borehole;

Fig. 2 shows similar apparatus adapted for recording two or more resistivity measurements simultaneously; and

Fig. 3 is a diagrammatic representation of a double-frequency apparatus adapted to perform two simultaneous measurements.

In Fig. 1 the feeding unit 1 of the equipment consists of a sinusoidal signal generator 13 operated by mains current obtained from an AC generator, or from some other source of current 14 which produces a sinusoidal measuring current of predetermined and of adequately low frequency to ensure little or no phase shift due to the cables. The signal generator 13 can advantageously be electronic and its output voltage adjustable to suit the operating requirements. One of the output terminals 12 is earthed at the surface, while the other active one is connected through a well logging cable 11 to a current electrode "A" in the borehole at the level of the formation to be surveyed. The points of connection to electrode "A" and

earth therefore constitute two survey supply terminals. The potentials appearing on the survey measuring electrodes M and N are conducted by two loads 21, 22, whose points of connection constitute survey measuring terminals, to the measuring amplifier 23 of a frequency selective character which is situated at the surface, in order to secure the selective amplification of the measuring frequency, while the disturbing voltages of other frequency bands originating from the mains or other sources are suppressed. The output voltage of the amplifier controls the phase-sensitive discriminator stage 24 connected to its output terminals. The output DC voltage of the discriminator 24 is proportional to the voltage components of the potentials between the measuring electrodes of the same frequency and phase position as the survey current, and contains no reactive phase disturbing voltage component. A recording instrument 25 is connected to the output terminals of the phase sensitive discriminator.

The measuring frequency is chosen so that the reactance of the input capacity of the well logging cable at the measuring frequency chosen is lower by at least one order than the highest apparent resistivity value to be measured. The signal generator will be used as a voltage generator of low output impedance, and series resistances for ensuring that the constant survey currents remain constant are connected into a section of the cable core supplying the survey currents to the boreholes at a position just before the current electrode A. This ensures that the phase angle of the voltage at the surface ends of the pair of supply leads does not change and ensures that the measuring currents from the current electrodes are predetermined and practically constant. The resistors may be adjustable and may have a value at least one order greater than the highest apparent resistivity to be measured.

In Fig. 2, the supply or feeding unit 1, the construction and components of which have been shown in Fig. 1, supplies a sinusoidal feeding current of constant intensity through lead 11 into current electrode A. Pairs of measuring electrodes M, N and M^1, N^1 are connected by insulated cables 21, 22 and 21^1, 22^1, respectively to the phase selective measuring circuits 2 and 2^1. The construction of the circuits is similar to that shown in Fig. 1.

In a similar way, by increasing the number of measuring cable-pairs, and the phase selective measuring circuits, an equipment with more than two channels can be constructed.

If it is intended to operate multi-channel apparatus having more than two channels it is necessary to provide various measuring channels each operating on a different frequency as shown in Fig. 3.

The current electrode A of one electrode set is fed from a signal generator 1 operating at a frequency f, and current electrode A^1 of another electrode set is fed from a signal generator 1^1 operating at frequency f^1 to supply the measuring currents of constant intensity. The potential appearing at the measuring electrode pairs M^1, N^1 and M, N is conducted to the phase selective measuring circuits 2 and 2^1 by two cablecores 21 and 22, M^1 being connected to M, and N^1 to N by separating ohmic resistances R and R^1, respectively, in a known manner. The input amplifiers of the phase selective measuring frequencies f and f^1, respectively. Thus, the measured potential values, which are transmitted to the surface by means of a common conductor-pair, can be separated from each other.

In this way an equipment with more than two channels can be constructed by utilising a corresponding number of sinusoidal signal generators and phase selective measuring circuits, and in this case only one pair of conductors or leads is needed for transferring the corresponding number of measured potential values.

Similarly with one terminal of each pair of supply terminals being earthed a common lead may be used for the signal generators.

In a further embodiment according to the invention the equipment comprises a D.C. voltage measuring and recording circuit suitable for measuring the natural potentials arising between any measuring point in the borehole and another measuring point at a distance or at the surface.

The components used in the various possible embodiments of the equipment according to the invention, i.e. the signal generators supplying the sinusoidal current, the phase selective circuits, and the recording device or measuring sondes can naturally be of any suitable standard design.

An adjustable output series resistor may be provided for the, or each, signal generator, its value being at least one order greater than the highest apparent resistivity value to be measured to facilitate adjustment of the respective output current. The output of the, or each, signal generator may be within the lower audio frequency band.

The technical characteristics of the measuring method and equipment according to the invention can be summarised as follows:—

Owing to the use of phase selective potential measurement, the equipment according to the invention facilitates the measurement of the resistivity by applying sinusoidal measuring current, while locating the equipment, with the exception of the measuring

electrodes, at the surface, and records simultaneously the resistivity at two or more sections.

WHAT WE CLAIM IS:—

1. A method of logging a borehole including the steps of sending low frequency sinusoidal alternating current through the ground between two current electrodes, providing a number of measuring electrodes down the borehole, providing frequency and phase selective amplifier means at the surface of the ground and connected to said measuring electrodes to receive therefrom voltage signals corresponding to said current, providing a resistor connected in series with one of the current electrodes, and supplying the amplified voltage signals to recording means, said resistor and said one current electrode being located in the borehole and said amplifier means being frequency selective so as to provide an amplified output of voltage signals substantially at said frequency and of a predetermined phase relationship to said current and to attenuate signals at other frequencies, and the value of said resistor being such that the maximum value of the alternating current is maintained substantially constant.

2. A method according to Claim 1 for making a number of simultaneous measurements, including the step of providing a plurality of pairs of insulated leads connected to the measuring electrodes, said plurality corresponding in number to the number of simultaneous measurements to be made, and providing a plurality of phase selective means equal in number to said number of measurements.

3. A method according to Claim 2 including the step of providing a plurality of pairs of measuring electrodes, each pair being connected to a different phase selective means by a separate pair of insulated leads.

4. A method according to any one of Claims 1 to 3 including the steps of providing a plurality of signal generators, each capable of producing a sinusoidal alternating current of a different frequency and each connected to a different pair of current electrodes, providing a corresponding plurality of phase selective means each adapted to select a different one of said frequencies, and providing, a plurality of resistors each connected in series with one of the current electrodes of a respective pair.

5. A method according to any one of the preceding claims including the step of connecting one electrode of the, or each, pair of current electrodes to earth at the surface of the ground.

6. A method according to Claims 4 and 5 including the step of connecting each of the current electrodes which is not earthed at the surface to the respective signal generator through a common lead.

7. A method according to Claims 4 and 5, or Claim 6 in which the measuring electrodes are connected to their respective phase selective means through a common pair of leads, resistive components being provided between corresponding electrodes of each pair.

8. A method according to any one of Claims 1 to 7 including the step of providing a D.C. voltage measuring and recording circuit suitable for measuring the natural potentials arising between any measuring point in the borehole and another measuring point at a distance or at the surface.

9. A method according to any one of Claim 1 to 8 in which the, or each, resistor is adjustable and has a value which is at least one order greater than the highest apparent resistivity value to be measured to facilitate adjustment of the output current of the respective signal generator, and the output of the, or each, signal generator is within the lower audio frequency band.

10. A method according to any one of Claims 1 to 9 in which the amplifier means includes one or more frequency selective amplifiers for selecting a respective voltage signal, each amplifier being connected to the input of a respective phase selective discriminator stage whose phase sensitivity is such that it ensures maximum attenuation of voltages which are displaced by substantially 90° with reference to the current supplied to the two current electrodes.

11. A method according to Claim 4, Claim 6 or Claim 7 in which a plurality of frequency selective amplifiers is provided each responsive to one of said frequencies and connected in parallel to the measuring electrodes, the number of amplifiers corresponding in number to the number of measurements to be performed, and a plurality of phase selective means being provided each connected to output terminals of a respective amplifier.

12. Apparatus for logging a borehole which is capable of making a number of simultaneous measurements of electrical resistivity including a signal generator located, in operation, on the surface for sending low frequency sinusoidal alternating current through the ground between two current electrodes, a resistor connected in series with one of the current electrodes, said resistor being located with respect to said one current electrode so that when in operation both are located within the borehole, and a plurality of pairs of measuring electrodes, at least one electrode of each pair being arranged, in operation, in the borehole, each pair of measuring electrodes being connected to a respective one of a plurality of phase selective circuit means equal in number to the number of simultaneous measurements to be made.

13. Apparatus according to Claim 12 including a plurality of pairs of measuring electrodes, each pair being connected to a different phase selective means by a separate pair of insulated leads.

14. Apparatus according to Claim 12 or Claim 13 including a plurality of signal generators, each capable of producing a sinusoidal alternating current of a different frequency and each connected to a different pair of current electrodes, the phase selective circuit means being provided each adapted to select a different one of said frequencies.

15. Apparatus according to any one of Claims 12 to 14 in which one of the, or each, pair of current electrodes is connected to earth at the surfaces of the ground.

16. Apparatus according to Claims 14 and 15 which each of the current electrodes which is not earthed at the surface is connected to the respective signal generator through a common lead.

17. Apparatus according to Claim 12 or Claims 14 and 15 as appendant to Claim 12 in which the measuring electrodes are connected to their respective phase selective circuit means through a common pair of leads separating resistors known *per se* being provided between corresponding electrodes of each pair.

18. Apparatus according to any one of Claims 12 to 17 including a D.C. voltage measuring and recording circuit suitable for measuring the natural potentials arising between any measuring point in the borehole and another measuring point at a distance or at the surface.

19. Apparatus according to any one of Claims 12 to 18 in which the, or each, signal generator is provided with an adjustable output series resistor having a value which is at least one order greater than the highest apparent resistivity value to be measured to facilitate adjustment of the respective output current, and the output of the, or each, signal generator is within the lower audio frequency band.

20. Apparatus according to Claim 19, in which the, or each, series resistor for adjusting the output current is, in operation, connected to the cable core supplying the feeding current in the borehole at a point just before the current electrode.

21. Apparatus according to any one of Claims 12 to 20 in which the phase selective circuit means includes one or more frequency selective amplifiers for selecting a respective voltage signal, each amplifier being connected to the input of a respective phase selective circuit, each phase selective circuit being a phase selective discriminator stage whose phase sensitivity is such that it ensures maximum attenuation of disturbance voltages which are displaced by substantially 90° with reference to the current supplied to the two current electrodes.

22. A method of logging a borehole according to the invention substantially as herein described with reference to Figure 1, Figure 2 or Figure 3 of the accompanying drawings.

23. Apparatus for measuring electrical resistivity in boreholes constructed, arranged and adapted to operate substantially as herein described with reference to Figure 2 or Figure 3 of the accompanying drawings.

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930,073 COMPLETE SPECIFICATION
1 SHEET

This drawing is a reproduction of the Original on a reduced scale.

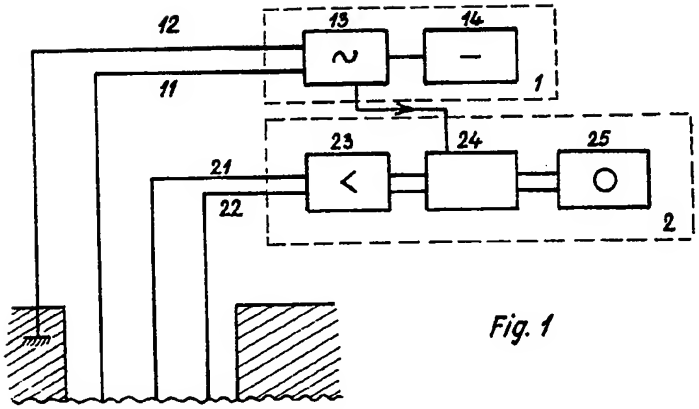

Fig. 1

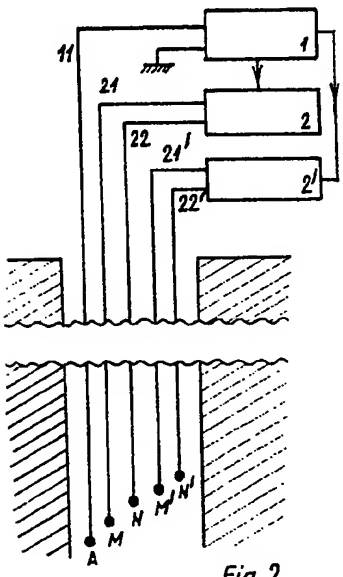

Fig. 2

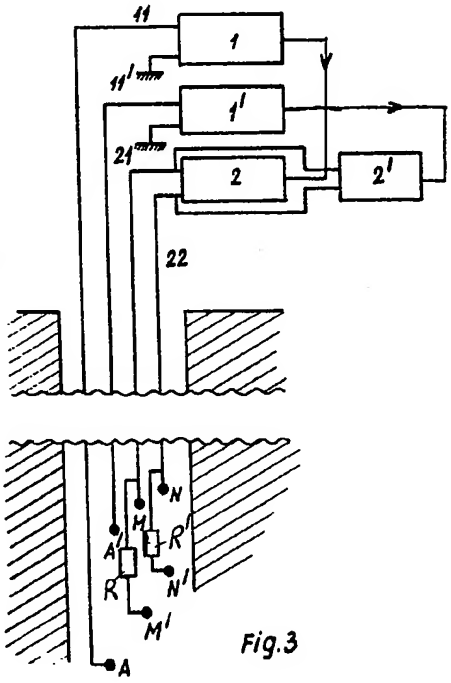

Fig. 3